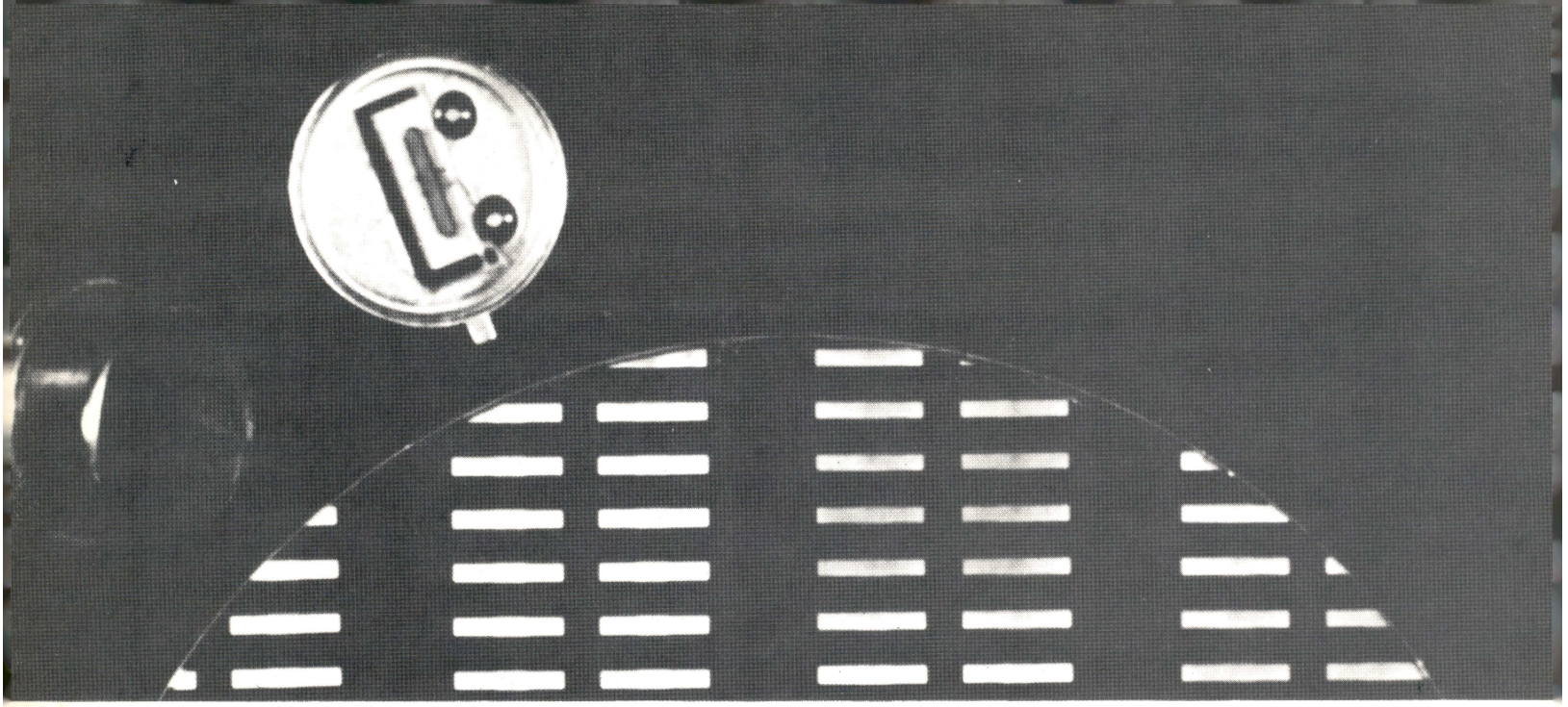
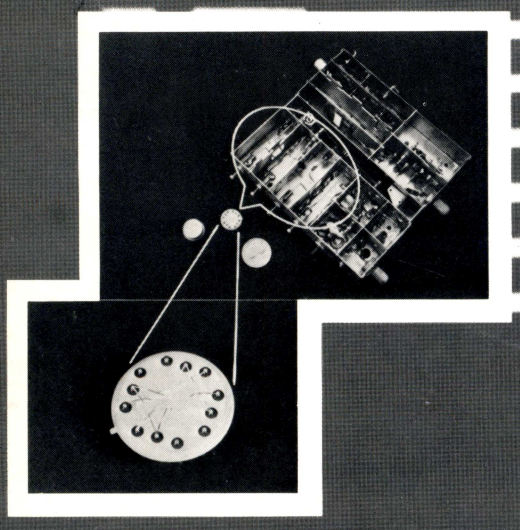


R F MONOLITHICS

SAW Filters



YOUR LOCAL REPRESENTATIVE
M. LADER COMPANY
456 Germantown Pike
Lafayette Hill, PA 19444
(215) 825-3177

RF MONOLITH

RF MONOLITHICS IS:

A young company dedicated to volume production of Surface Acoustic Wave (SAW) devices and subsystems based on SAW devices operating in VHF – UHF. RFM is the premium source for users of SAW devices for two reasons: (1) Low cost, and (2) Performance.

COST:

SAW technology to date has provided products to military and limited commercial users in the 50 to 400 MHz frequency range, with prices in the hundreds of dollars. Certain off-shore manufacturers have produced SAW filters limited to TV receivers at 40 MHz in the one dollar range.

However, RFM stands alone with its state-of-the-art semiconductor production equipment for SAW fabrication with capabilities available in large quantities and unit prices dropping to only a few dollars.

PERFORMANCE:

RFM possesses the engineering technology and production facilities to deliver the high performance units needed today. The inventions of the unidirectional transducer for low-loss transversal SAW bandpass filters and the SAW resonator used for controlling the frequency of RF oscillators are the work of the founders of RFM. The combined exclusive ability to design and produce these items in large quantity places RF Monolithics in a unique position.

THE SAW CONCEPT

Simply stated, a surface acoustic wave is a high-frequency sound wave that traverses the polished surface of a piezoelectric crystal substrate. Electrical to acoustical energy conversion is accomplished in interdigital transducers deposited on a substrate as shown in Figure 1.

These first generation devices have only limited penetration into the consumer and commercial area due to relatively high insertion loss and triple-transit echoes, producing phase and amplitude ripple in the passband of some SAW transversal filters.

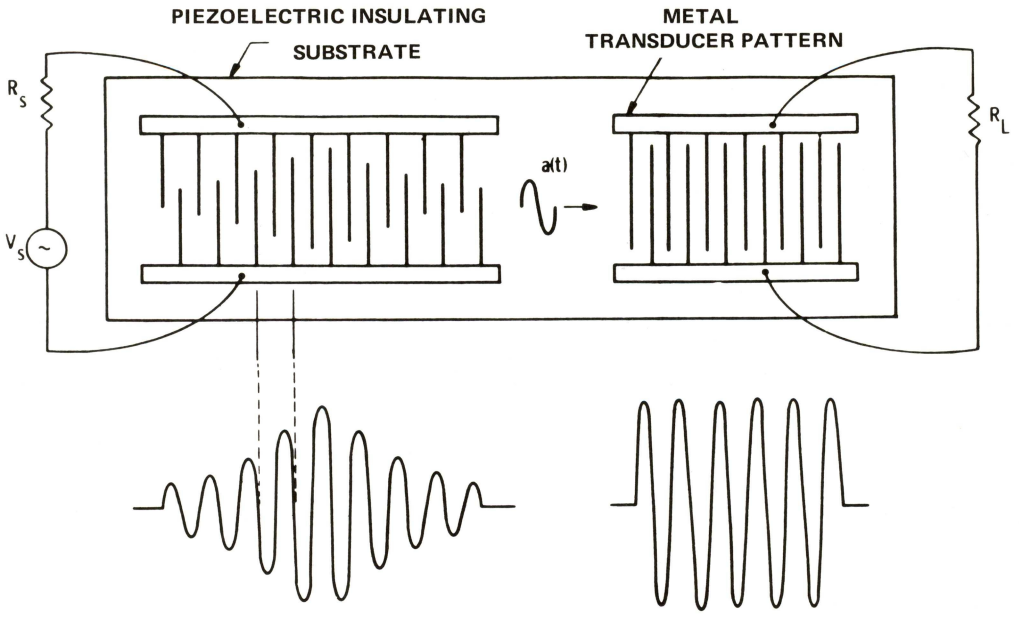
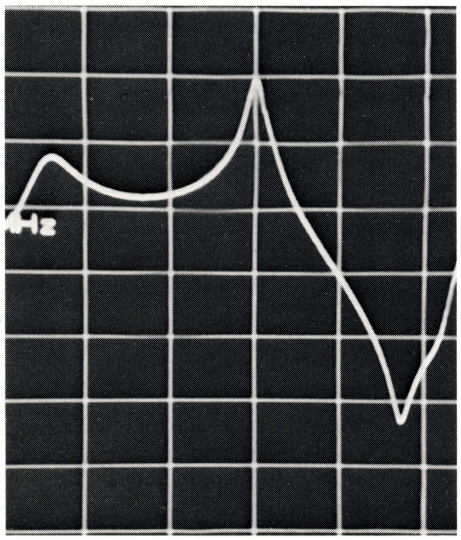


FIGURE 1: First-generation transversal SAW device with bidirectional transducers. Insertion loss is typically in the 25dB range.

Product Bulletin

SURFACE ACOUSTIC WAVE RESONATORS

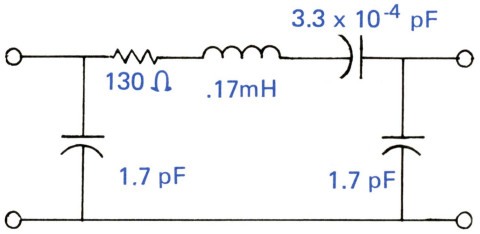


Frequency response of a two-port 674 MHz SAW resonator.

THE SAW RESONATOR

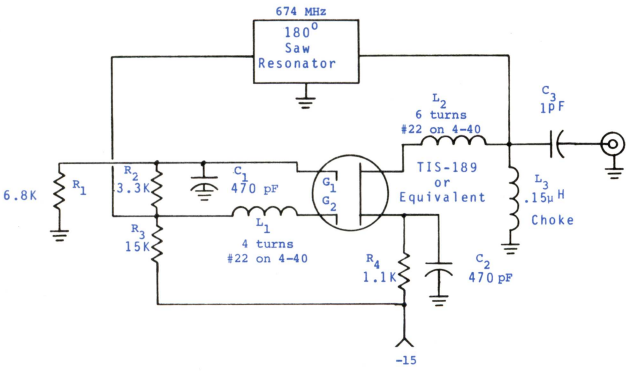
A resonator is a narrow-band device useful as the frequency control element of a stable, low-cost oscillator and as a very narrow band-pass filter for applications in the VHF — UHF (100 - 1000 MHz) range.

A SAW resonator consists of two reflective gratings forming a resonant cavity with transducer coupling of energy into and out of the cavity. The typical unloaded Q range is from 50,000 to 5,000 depending on center frequency, reflector array size, and other factors.



The two-port SAW resonator equivalent circuit consists of a series resonant circuit with a series Q-determining resistor and shunt capacitances to ground at each port.

SAW RESONATOR OSCILLATOR



The high Q and low spurious modes exhibited by SAW resonators make them ideal frequency references for oscillator circuits. A single transistor amplifier with simple tuned input and output circuits is all that is required in addition to the SAW device to realize a stable UHF oscillator. SAW resonator oscillators are presently in mass production for stabilizing cable television convertors.

SAW RESONATOR OSCILLATOR ADVANTAGES

- **Voltage tunable over ±.025% range.**
- **Stable.**
- **Repeatable.**
- **Compact size.**
- **Less sensitive to shock.**
- **Higher Q than SAW delay line or LC.**
- **Lower loss.**
- **Simpler circuit.**
- **Lower power consumption.**

TYPICAL SPECIFICATION RANGE

Frequencies	—	**Up to 1000 MHz**
Q_u	—	**50,000 to 5000**
Temp Stability	—	$\left[\frac{T-T_0}{5.6}\right]^2$ **ppm (°C)**
Aging	—	**1 to 10 ppm/yr @ 40°C**
Insertion Loss (load dependent)	—	**1 to 15dB**
Spurious Responses	—	**10dB min.**
Phase	—	**0° or 180°**
		50 Ohm sys (Specify)

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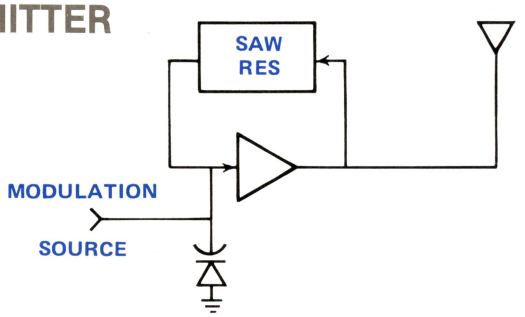
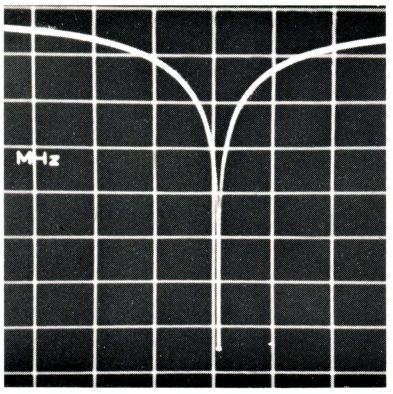
ADDITIONAL SAW RESONATOR APPLICATIONS

TRANSMITTER

A low-cost transmitter, achieved with simplicity using a SAW resonator.

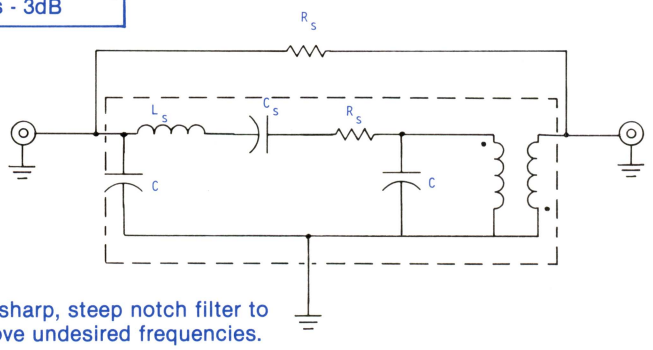


NOTCH FILTER



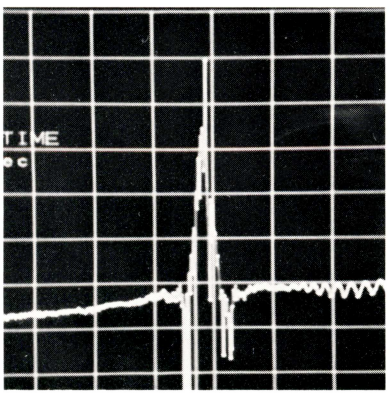
Center Freq. - 674 MHz
Signal Loss - 3dB

SAW RESONATOR NOTCH FILTER USING 180° SAW RESONATOR

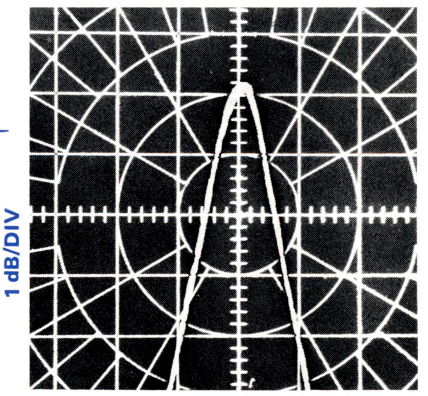


As a sharp, steep notch filter to remove undesired frequencies.

NARROW FILTER



Frequency - 150 MHz
Signal Loss - 6dB



A very narrow filter with deep rejection, shown into a 50 ohm load. Band width is load-dependent.

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Texas Company Enters SAW Market

REPRINTED FROM OCTOBER 1981 MSN MAGAZINE.

A Dallas company begun in March 1979 sees itself as a major contender in the Surface Acoustic Wave (SAW) market. Clinton Hartmann, Lawrence Ragan, and Darrell Ash began RF Monolithics (RFM) with the intent to bring SAW resonators and high selectivity, low-loss VHF and UHF filters to the commercial marketplace. They perceived the need for receiver design freedom that their SAW products will permit.

Hartmann, now chief executive officer (CEO) of the company, invented and was responsible for the development of two fundamental SAW devices: the low-loss SAW filters, and the SAW resonator. One of the company's first programs was an advanced television tuner development project, sponsored by the FCC, using SAW devices. With the successful completion of the program, interest was aroused from other manufacturers. Subsequently, the FCC awarded a "follow-on" contract, now nearing completion, which has resulted in further refinements of both the resonator and filter, and a simpler receiver with improved performance.

Fifteen months after founding, funding was secured to set up the quantity SAW production facilities. The SAW processing facility is unique in SAW technology. It uses the latest automated semiconductor manufacturing equipment to process 3-inch wafers with a potential throughput of over a million devices per month. Facilities include cassette to cassette processing for all major operations and fully automatic processing for most critical stages. Both hard and soft contact alignment is used for line sizes of less than 1 micron. Accurate metal deposition (thickness control to better than ± 2 percent) is achieved using RF sputtering.

A surface acoustic wave resonator provides a stable frequency control for VHF-UHF oscillators.

With this type of facility, according to Bob Stigall, vice president of production, linewidth reproducibility required to obtain good yield in high-frequency devices is possible for the first time. Computer-aided test facilities have been developed that boost yields as well as guarantee quality. CAD routines have been developed that allow rapid device design and mask fabrication, with prototype turnarounds of approximately four weeks for straightforward designs.

Initial work in the high-performance television receiver provides the basis for continued applications support for customers with requirements for low-cost, high-performance receivers and low-power transmitters. Marketing is the key to the success of this venture, and markets that require large quantitites of high-performance filters with costs less than $10 (many less than $5) will be supportive. These prices represent a significant reduction from the $30 to $100 projected by the military 3M program (see *MSN*, October 1977) for devices which have higher performance. As first customers require narrowband filters for cable TV converters, the market has the potential for more than 1 million devices a year and industry growth could greatly expand this figure. Future applications include low-cost receivers using a wideband RF frontend with high-frequency, low-loss IF filters ($\approx$ 600 MHz) for good image separation, and wide tuning range without retuning the RF frontend.

The company expects the SAW market to expand rapidly, and intends to be a major vendor of new, high-performance SAW products.

RFM

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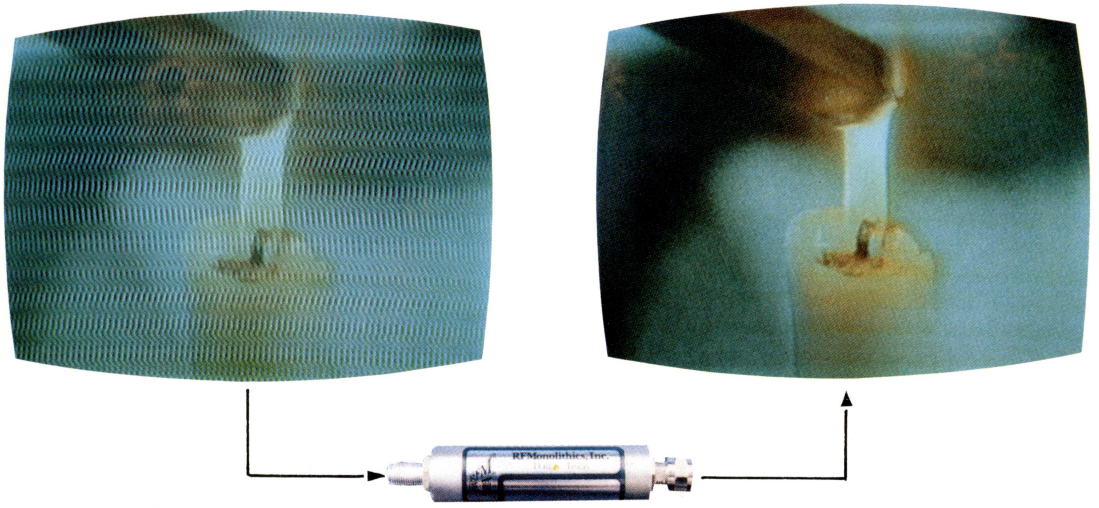
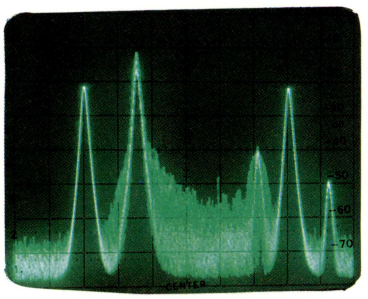
Product Bulletin

CONVERTER OUTPUT FILTER

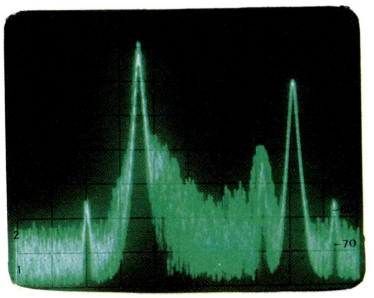
ELIMINATES ADJACENT CHANNEL INTERFERENCE USING SAW TECHNOLOGY



CTVF-3



The dramatic results of the rejection ability of the CTVF-3 is illustrated by these unretouched photos!



There are combinations of certain TV sets & converters which allow interfering adjacent channel signals into the receiver at strong amplitude levels, causing a poor picture & an unhappy subscriber.

The Model CTVF-3 sharp cut-off filter rejects all but the desired receiver input forever, & puts an end to service calls because of complaints about those interfering signals.

Simple to use — just attach it to the converter output connector & put the existing cable on the output of the filter. No need to install a new converter!

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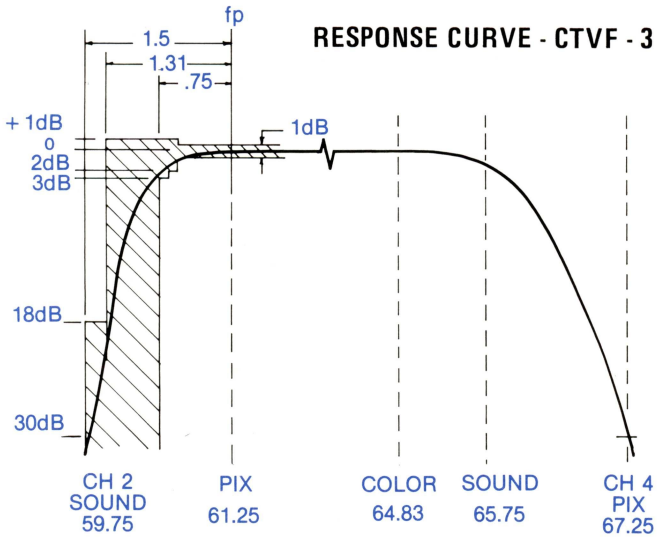
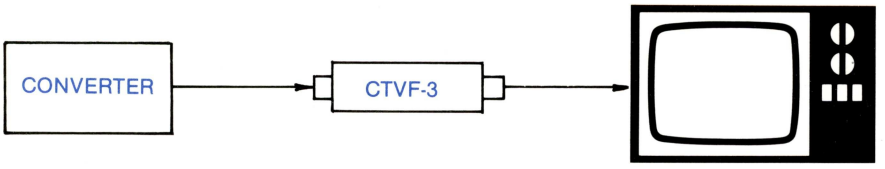
RESPONSE CURVE - CTVF - 3



SPECIFICATIONS	CTVF-2	CTVF-3	CTVF-4
• Output	CH 2	CH 3	CH 4
• Adjacent Channel Rejection	30 dB		
• Desired Signal	Picture & Sound in Pass-Band, within 1 dB of peak signal.		
• Insertion Loss	5 dB Max.		
• Output VSWR	1.5:1		
• Impedance	75 ohms		
• Connectors	"F" Type (Specify M-F or F-F)		
• Dimensions	3" L x 7/8" Diameter		

INSTALLATION



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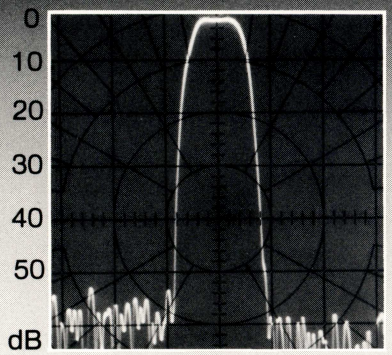
S A W

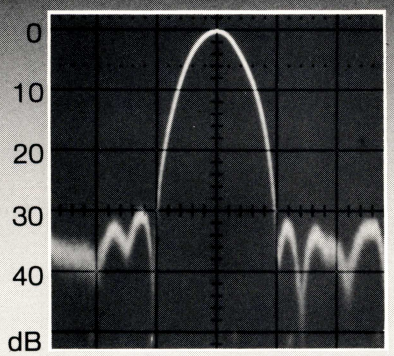
AT LAST...
HIGH QUALITY
SURFACE ACOUSTIC WAVE DEVICES
YOU CAN AFFORD



4 MHz/Div.

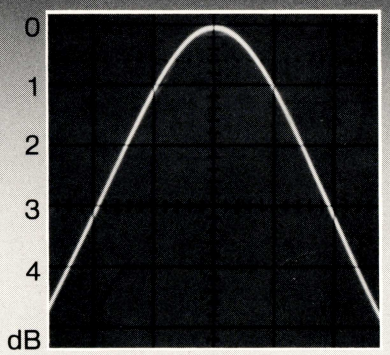
446 MHz SAW Filter
(TV Receiver)

VHF-UHF bandpass filters provide superior adjacent channel rejection with an insertion loss as low as 4dB: frequencies to 600 MHz.



1 MHz/Div.

65.75 MHz SAW Audio Filter
(CATV Converter)



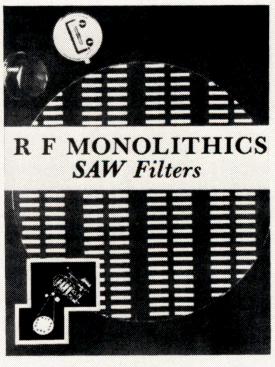
20 KHz/Div.

600 MHz SAW Resonator
(CATV Converter, 2nd LO)

SAW resonators for use in oscillator frequency control provide a stable frequency source at low cost: frequencies to a GHz, unloaded Q to 50,000.

RF Monolithics is dedicated to production of SAW devices using state-of-the-art facilities. If you have a high-volume need, we can provide you with cost-effective high-performance SAW components.

Need to know more? Just give us a call.



Send for our New brochure!

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"To provide stability in frequency output for our new cable television series 6700 set-top terminals, we felt we needed SAW resonators," explained Mr. Kelly. "But there were a couple of problems. We not only needed the resonators in high volume, but we needed them in a hurry.

"So, we spoke with RF Monolithics. They said they could solve the problem. That's one of the points we liked best about them, right away. They've got a unique problem-solving attitude.

"They began to work closely with our engineers to make sure that our requirements and costs were coordinated. They even went beyond the device and helped with circuit application assistance, too. Yet, they continued to make sure that everything was cost beneficial to both of us.

"We gave RFM some tough problems. But they met every challenge we gave them. They produced the amounts of high-quality resonators we needed and on schedule.

"RFM did what they said they could do. They helped solve a difficult problem for us. That's why we plan to continue with them."

To find out more about our second generation resonators and low-loss filters in the UHF/VHF range, write RF Monolithics, 4441 Sigma Road, Dallas, TX 75234. Or phone (214) 233-2903.

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4441 Sigma Road
Dallas, Texas 75234
214 233-2903

"When we needed high volumes of SAW resonators fast, only one company could deliver. RF Monolithics."

—Jack Kelly, Executive Vice-President
Scientific-Atlanta

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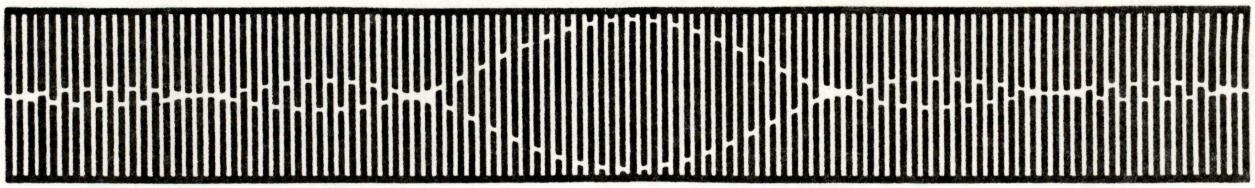
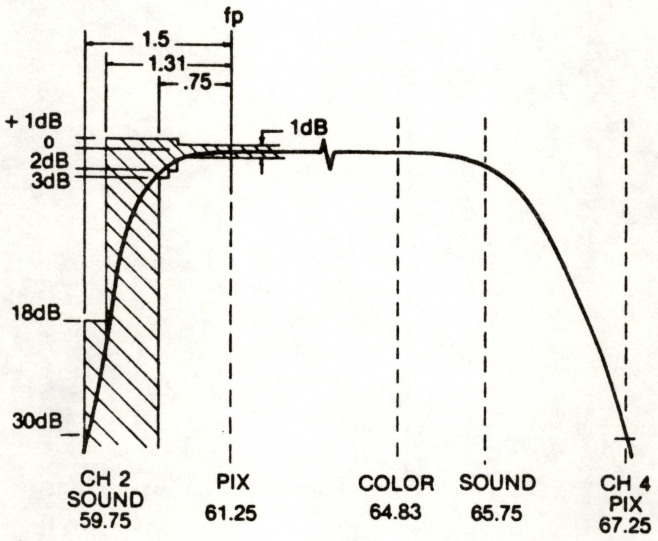
PRODUCT BULLETIN



SHARP CUT-OFF FILTER

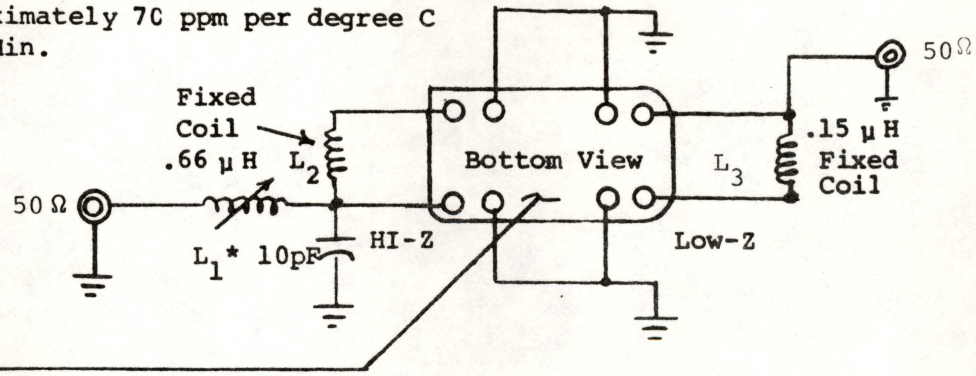


RESPONSE CURVE, FILTER # ML-1002

Also:

Channel 2 - P/N ML-1003
Channel 4 - P/N ML-1004

Insertion Loss:	10dB Max., 8 typical, Matched in Recommended Circuit
Group Delay:	± 100 nsec Max.
Temperature:	Variation dependent on lithium niobate substrate - approximately 70 ppm per degree C
Triple Transit:	40dB Min.



LOW LOSS FILTER

MATCHING CIRCUIT SCHEMATIC

Dimensions

L - .8"
W - .5"
H - .2"
Pins - 14-Pin DIP (Type)

* 4.5 Turns on Coilform Company #Z-216001 10-32 Velvetork, .375" Long Coil Form

w/Micrometals #TH 35 - 0206 Core

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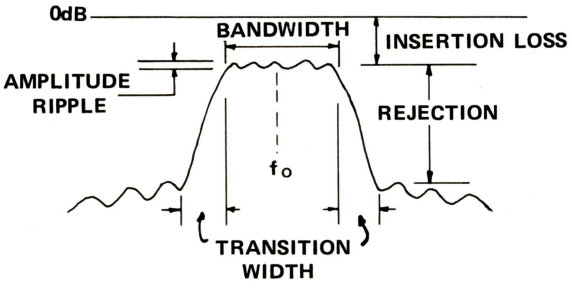
SPECIFICATIONS — APPLICATIONS

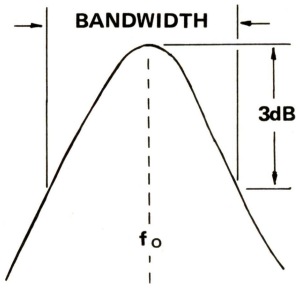
LOW–LOSS BAND–PASS FILTER



TYPICAL SPECIFICATION RANGE

Center Frequency	–	45 – 1000MHz
Bandwidth (1dB)	–	up to 20% f_o
Insertion Loss	–	4 – 6dB
Transition Width	–	300 kHz to 3MHz
Amplitude Ripple	–	0.1dB up
Rejection	–	20 – 50dB
Package	–	TO – 8
Triple Transit	–	45dB min
Temperature Stability		$\left[\frac{T-T_o}{5.6}\right]^2$ppm (°C)

SINGLE POLE SAW RESONATOR RESPONSE



TYPICAL SPECIFICATION RANGE

Frequencies	–	Up to 1000 MHz
Q_u	–	50,000 to 5000
Temp Stability	–	$\left[\frac{T-T_o}{5.6}\right]^2$ppm (°C)
Aging	–	1 to 10 ppm/yr
Insertion Loss (load dependent)	–	1 to 15dB
Rejection	–	20dB
Package	–	TO-5

SAW APPLICATIONS

- *TV receivers*
- *STV descramblers*
- *Pagers*
- *Radar pulse compression*
- *Fixed code filters*
- *Convolvers*
- *Mobile communications*

SAW RESONATOR OSCILLATOR ADVANTAGES

Resonator - Oscillator is ––

- Voltage tunable over ± .025% range.
- Stable.
- Repeatable.
- Compact size.
- Less sensitive to shock.
- Higher Q than SAW delay line or LC.
- Lower loss.
- Simpler circuit applications.
- Lower power consumption.

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ICS SAW FILTERS

THE RF MONOLITHICS WAY

Now, second generation SAW devices, exemplified by two major inventions by RFM personnel, have completely changed the way SAWs are made and used.

A major disadvantage of the first generation SAW filter is relatively high insertion loss (10 to 35 dB) due primarily to the bi-directional wave mode and impedance mismatch. The filter (Figure 1) uses interdigital fingers spaced at one-half wavelength resulting in bi-directional propagation of acoustic energy on the substrate surface. Attempts to impedance match the electrical output port to its load results in a regenerated signal back to the transmit transducer, showing up as a large in-band ripple in the filter response. To prevent this, the transducers are loaded with impedance much lower than their internal impedance, causing high insertion loss.

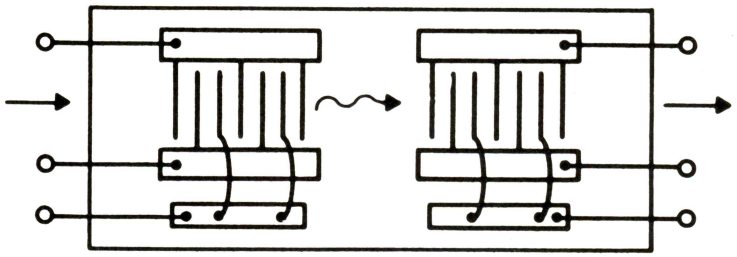


FIGURE 2: Second-generation transveral SAW device with unidirectional transducers. Typical insertion loss is 4dB.

THE SAW LOW–LOSS TRANSVERSAL FILTER

The low-loss filters produced by RFM make use of the multi-phase unidirectional transducer (Figure 2), producing acoustic energy propagated in one direction only, suffering none of the bi-directional losses. The transducer is now essentially a two-port element which may be perfectly matched to its load with no reflections. The only remaining losses are those of parasitic resistances, diffraction, and acoustic propagation, with typical device losses reduced to between 3dB and 6dB.

A three-phase low-loss transducer is shown in Figure 3. The fabrication of multiphase transducers is somewhat complex due to the low-capicitance cross-over, but may be processed using leading-edge semiconductor fabrication techniques with high yields at high frequencies. Some 500 such cross-overs per transducer are routinely produced. A slice fabrication process produces over 100 filters per slice.

Temperature-stable quartz substrate is popularly used in SAW filters. Other materials can be used, however, if wider bandwidth is desireable at the expense of temperature stability. Typical fractional bandwidth/insertion-loss is shown in Figure 4 for various substrates.

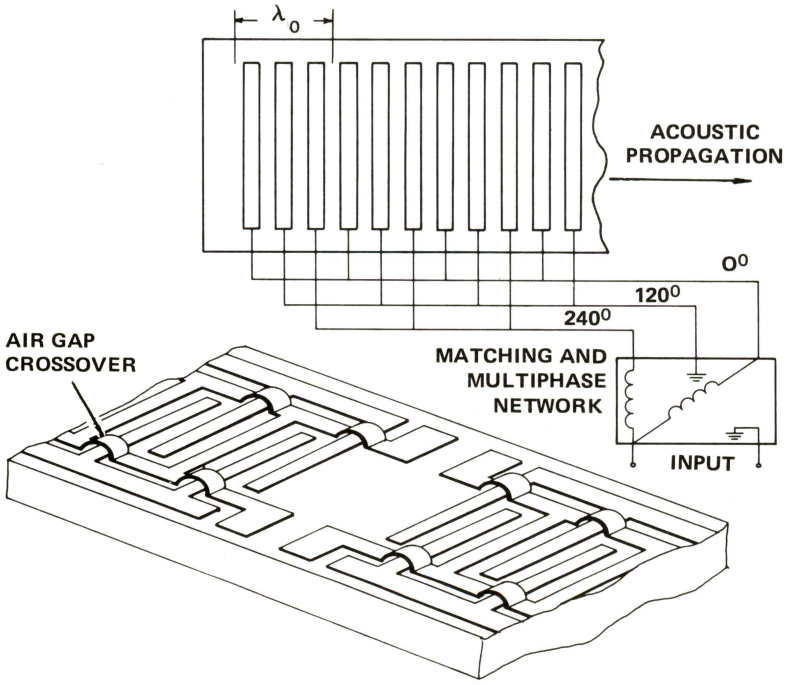


FIGURE 3: Low-loss unidirectional transducer with air-gap crossover and multi-phase matching network.

Coupling of the standing wave energy into and out of the cavity is through the use of interdigital transducers. The use of two transducers for separate input and output coupling greatly reduces direct feed-thru problems at UHF.

THE SAW RESONATOR

A resonator is a narrow-band device useful as the frequency control element of a stable, low-cost, oscillator and as a very narrow band-pass filter for applications in the VHF – UHF (100 - 1000 MHz) range.

With the acoustic energy confined to a shallow area at the crystal surface, all the critical device parameters are determined by patterns on that surface. To create resonance, two arrays of grooved reflectors define the cavity. The forward-propagating Rayleigh wave is scattered into a backward propagating mode by the distributed reflectors without creating significant energy in other acoustic modes. The two grooved gratings shown in Figure 5 thus set up a large amplitude standing wave at a precisely defined resonant frequency.

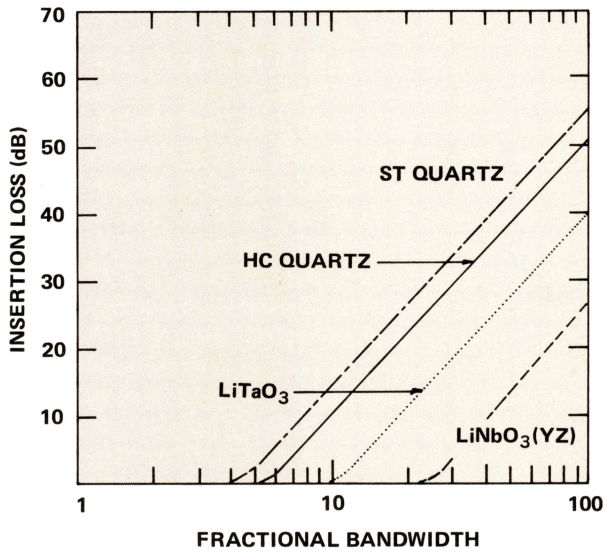


FIGURE 4: Theoretical minimum insertion loss for various substrates utilizing the unidirectional transducer.

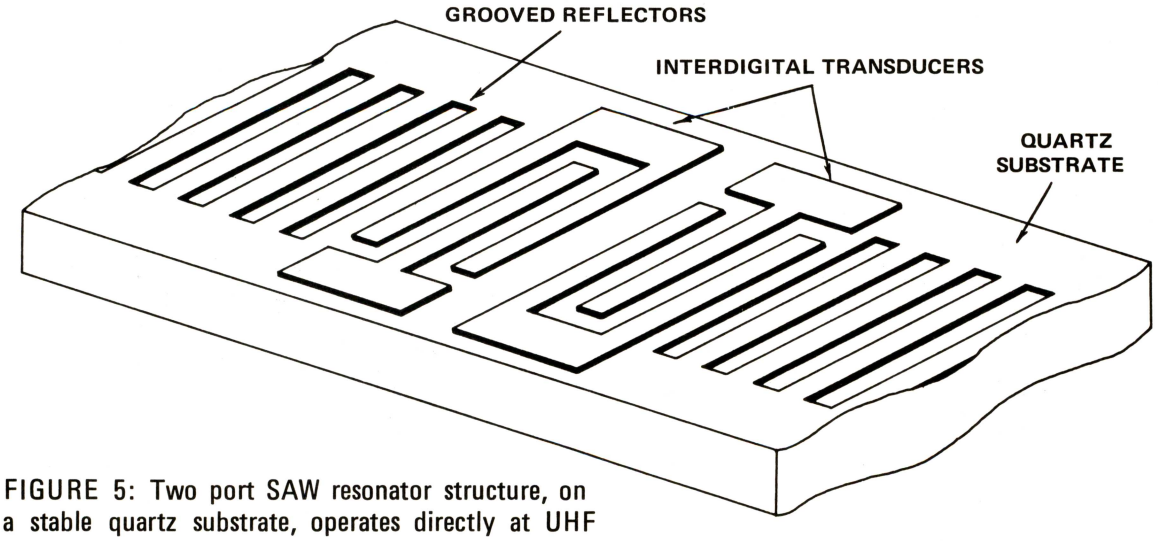


FIGURE 5: Two port SAW resonator structure, on a stable quartz substrate, operates directly at UHF frequencies.

Resonant bandwidth is essentially determined by the RLC relationship in Figure 6. The bandwidth may be altered by changing the source and/or load resistance (R_s, R_L) typically 50 OHMS. Unloaded Q (Q_u) may be defined as:

$$Q_u = \frac{\omega L}{R}$$

where $\omega = 2\pi f_0$

Loaded Q (Q_L) appears as:

$$Q_L = \frac{\omega L}{R_I + R_s + R_L}$$

Roughly determined, Q_L will be approximately equal to resonant frequency divided by bandwidth.

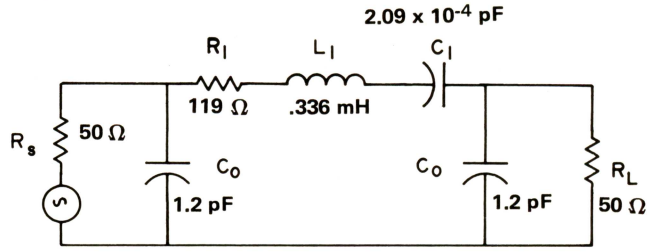


FIGURE 6: Two port SAW resonator equivalent circuit.

The SAW resonator naturally leads to the simple low-cost oscillator shown in Figure 7. Needing only an amplifier to complete the oscillator, the resonator boasts very high unloaded Q, and low-loss. Typical resonator response is shown in Figure 8.

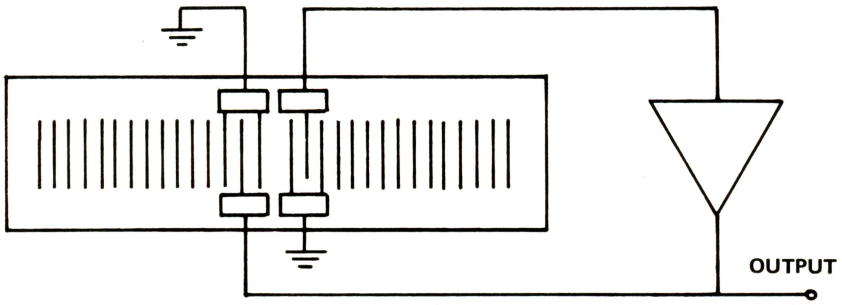


FIGURE 7: Oscillator schematic.

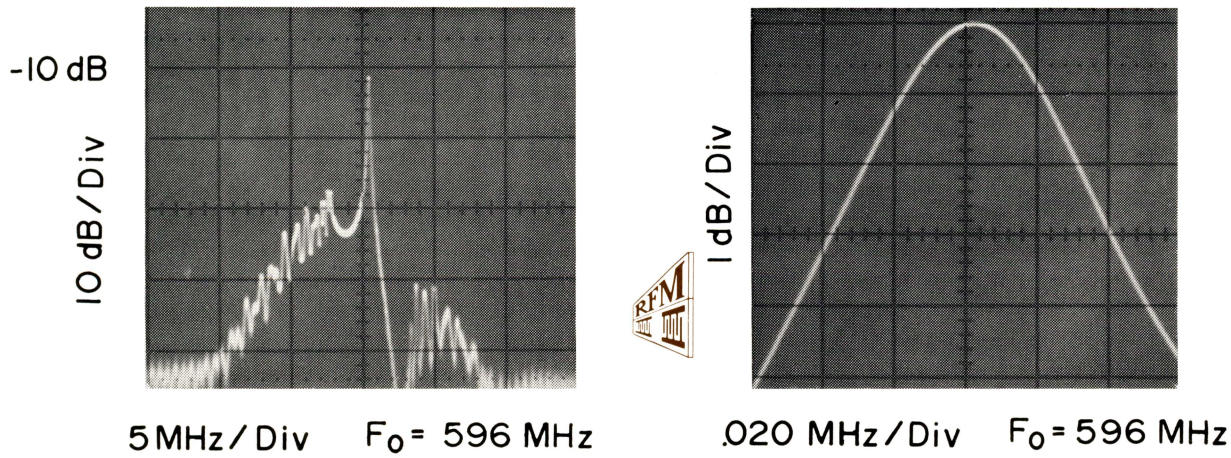
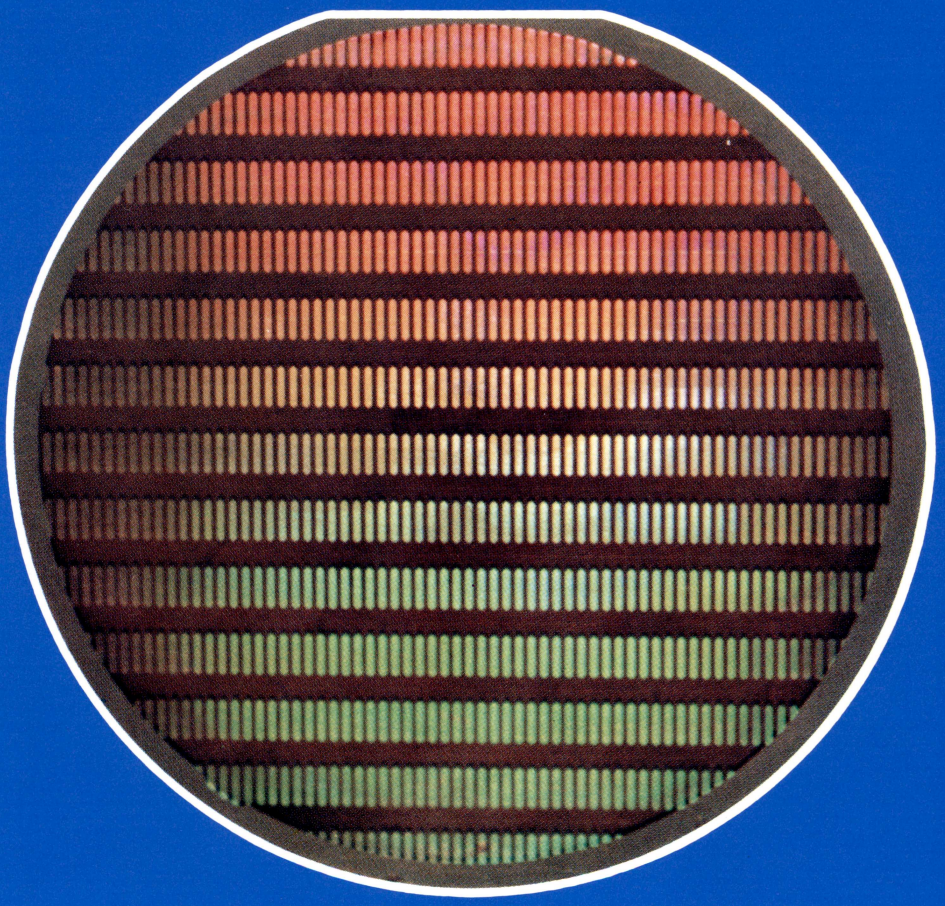


FIGURE 8: 596 MHz two port SAW resonator-frequency response.

RF Monolithics

Surface Acoustic Wave Applications



This is a completed three-inch wafer of 680 megahertz resonators prior to cutting. The colors are due to light diffraction by the one micron lines deposited on the substrate.

REPRINTED FROM R.F. DESIGN MAR / APR 1982*

SAWS!

By Darrell L. Ash
Vice President Engineering
and Richard H. McLean
Director of Sales
RF Monolithics
Dallas, Texas

When Surface Acoustic Wave devices entered the marketplace some 15 years ago, first applications were found in certain government-related programs where the initial high cost could be justified by the size/performance advantages they offered.

Tediously fabricated and produced in small quantities, outstanding performance was achieved in applications such as radar signal processing and high resolution countermeasures receivers. Further applications have been successful in major U.S. Defense Programs, making use of SAW delay line oscillators and SAW correlators for spread-spectrum communications.

During this period, low-frequency SAW filters found use in television receivers in large quantities and at very low cost.

These "First-Generation" series of designs generally resulted in size-efficient filters, generally below 100 MHz

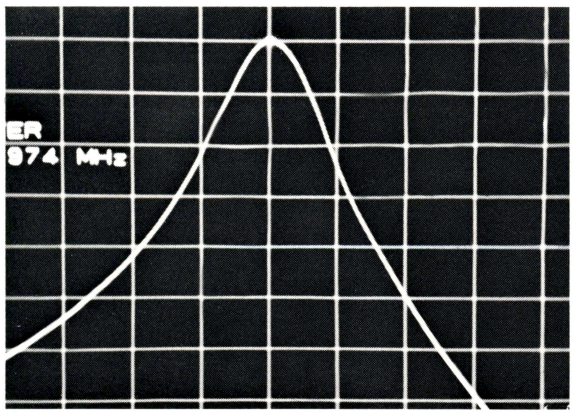


Figure 1A. SAW Resonator Frequency Response.

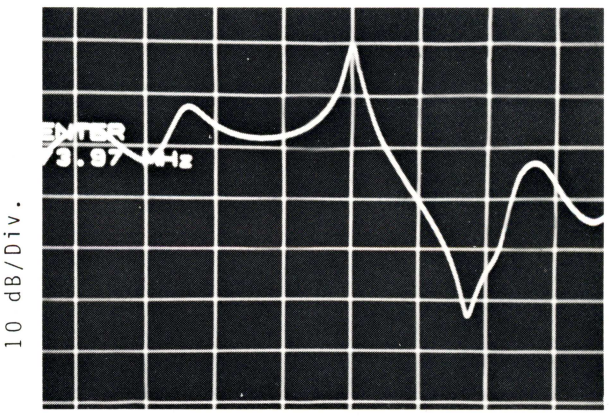


Figure 1B. SAW Resonator Frequency Response.

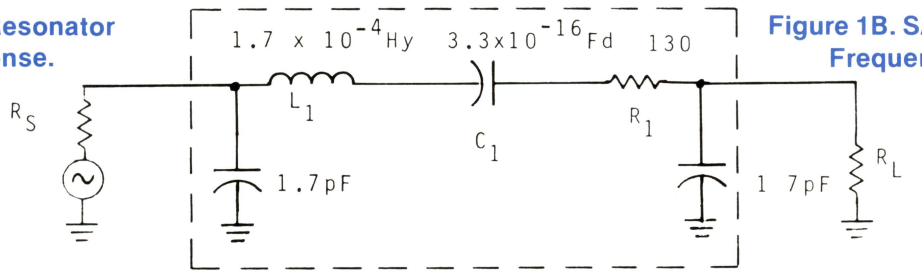


Figure 1C. SAW Resonator Equivalent Circuit.

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POWERFUL PASSIVES

Second generation SAW filters are providing powerful new alternatives in circuit design.

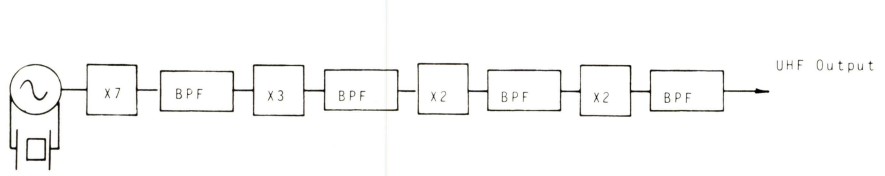


Figure 2A. Conventional Crystal Oscillator & Multiplier Chain.

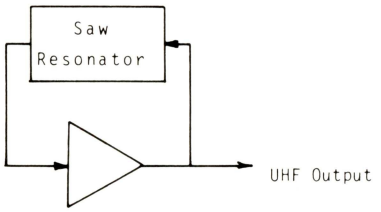


Figure 2B. SAW Resonator Oscillator.

and usually exhibiting insertion loss figures in the 25 dB area. Given this background, a new awareness began among communications engineers of the benefits in using the technology, requiring less than the exotic designs necessary for reflective array correlators but more powerful devices than the mass-produced video IF TV filters.

This discussion, then, will address the fastest growing segment of SAW applications, generally defined by the frequency boundaries of 40 MHz to 1000 MHz which are being placed into use by the commercial communications industry.

These newer designs may be termed "Second-Generation," in that filters may be produced in the mid-100 MHz frequency range, smaller in size and with much reduced signal loss than their first generation counterparts. Also defined by the second generation label are SAW resonators for use as the frequency-control element for size-and-cost-efficient oscillators, operating directly at frequencies to 1 GHz, while at the same time eliminating crystals, multiplier chains and amplifier stages.

SAW Resonator Applications

A SAW Resonator consists of two reflective gratings forming a resonant cavity with transducer coupling of energy into and out of the cavity. The typical unloaded Q range is from 50,000 to 5,000 depending on center frequency, reflector array size, and other factors. Center frequencies up to 1000 MHz are attainable within that Q range. Figure 1 includes photographs of the frequency responses of a two port 674 MHz resonator, presently being mass produced, as well as its equivalent circuit. The equivalent circuit (within the dash lines) consists of a series resonant circuit with a series Q-determining resistor and shunt capacitances to ground at each port.

The high Q and low spurious modes exhibited by SAW resonators make them ideal frequency references for oscillator circuits. Figure 2A is a block diagram of a crystal oscillator and frequency multiplier chain which is typical of the approach presently used to obtain a stable, fixed UHF output for local oscillator or transmitter applications. Figure 2B is a block diagram of a SAW resonator oscillator with the same UHF output. Figure 3 is a schematic diagram of a SAW oscillator circuit presently in mass production

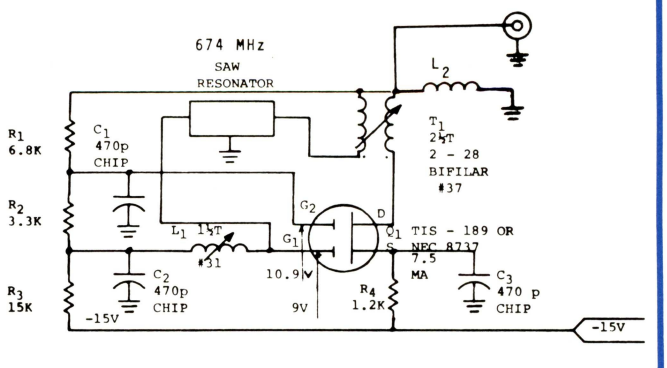


Figure 3. Present SAW Resonator Oscillator.

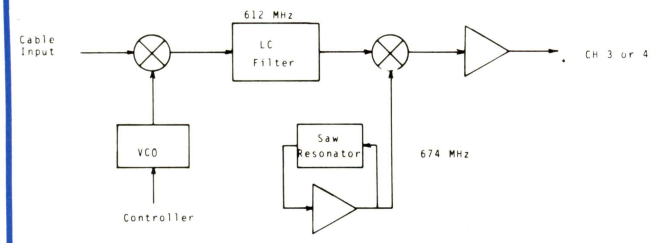


Figure 4. Cable TV Converter.

which accepts resonators with center frequencies from 674 MHz to 680 MHz. The simplicity of the SAW resonator oscillator compared to the crystal oscillator and multiplier chain is obvious. A single transistor amplifier with simple tuned input and output circuits is all that is required in addition to the SAW device to realize a stable UHF oscillator.

Use in Cable TV

The circuit of Figure 3 is presently being used to provide a stable second local oscillator for cable TV converters as illustrated in the block diagram of Figure 4. A stable second local oscillator is needed in cable converters to maintain an output within the AFC pull-range of television receivers using frequency synthesizers and also to interface with descrambler circuits. A 674 MHz L.O. at the second mixer produces a converter output on Channel 3.

Referring to Figure 3 again, the SAW resonator used in this circuit has a phase shift of 0° at the resonator center frequency. The transformer, T1, and inductor, L1, are adjusted to yield a 0° phase shift around the oscillator loop. T1 consists of an air core bifilar-wound coil which couples a portion of the output power back to the amplifier input through the SAW device. A dual gate FET device is used for the amplifier to present a large Q-reducing impedance to the resonator. This particular circuit can be pulled more than 200 kHz by adjusting T1. One disadvantage of this circuit is that it will oscillate only on the high side of the resonator response. Excess phase shift in the transistor (approximatey 240° rather than 180°) must be compensated for by using part of the phase slope of the resonator device on the high side of resonance to obtain 0° phase shift around the oscillator loop, since the external tuning elements have too much attenuation at the required phase shift.

The more recent oscillator circuit of Figure 5 can be pulled through the resonator center frequency to either side of resonance. This oscillator uses a resonator device which exhibits a 180° phase shift at its center frequency. The series inductors, L1, and L2, in conjunction with the transistor input and output capacitances and the input and output capacitances of the resonator yield the necessary phase shift around the oscillator loop to compensate for the excess phase shift in the transistor. This oscillator can also be pulled more than 200 kHz by adjusting L2.

Other Uses for the Resonator

The block diagram of Figure 6 illustrates another use for such a SAW stabilized oscillator. A very low cost, single transistor, low power (>0 dBm), stable, FSK transmitter can be realized by adding a varactor diode to pull the oscillator in response to a modulation source.

SAW resonators can also be used as narrow band band-pass filters. The block diagram of Figure 7 illustrates how a narrow band receiver can be greatly simplified by using a SAW resonator filter. Most narrow band receivers cannot take advantage of low cost 455 kHz IF filters for the first IF because the resulting image frequency at 910 kHz is too close to the desired frequency to be filtered out in the RF filter in front of the first mixer. Thus, double conversion is usually used in such receivers (10.7 MHz for the first IF and 455 kHz for the second IF). Referring to Figure 1B, the notch on the high side of the resonator response can

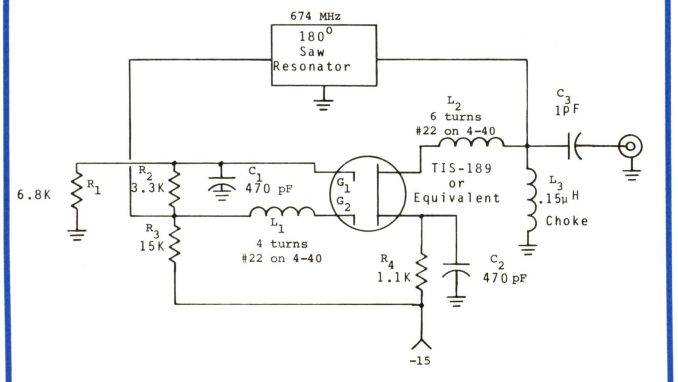


Figure 5. New SAW Resonator Oscillator.

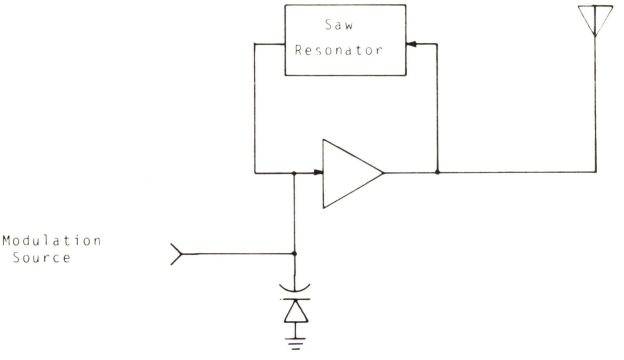


Figure 6. Low Cost Transmitter.

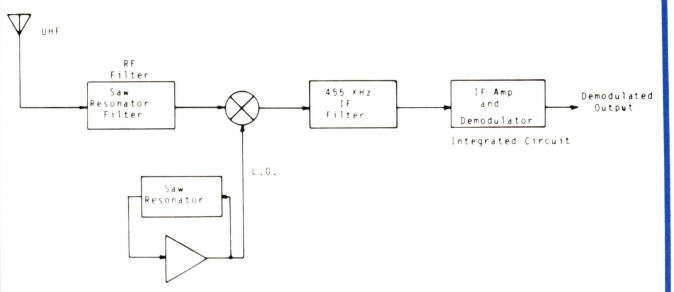


Figure 7. SAW Resonators in Simple Narrowband Receivers.

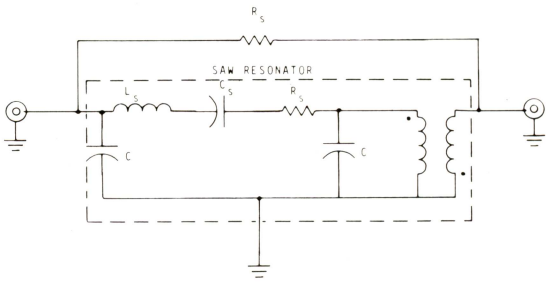


Figure 8. SAW Resonator Notch Filter.

be placed 910 kHz above the response by a simple design change. Thus, an image rejection of ~50 dB would be obtained at RF with a single resonator filter. Of course, a SAW resonator could also be used for the local oscillator rather than a crystal oscillator and multiplier chain which would further simplify the receiver. The result is a very low cost, high performance, narrow band receiver.

Notch Filter

Figure 8 schematically illustrates how a SAW resonator with 180° phase shift at center frequency can be used in a narrow notch filter configuration. A feedback resistor is added whose resistance is equal to the internal resistance of the resonator. This produces a null at the resonator center frequency. The pass-band insertion loss is the loss of the feedback resistor. A lowpass filter network making use of the resonator shunt input and output capacitance can be added to the simple circuit of Figure 8 to further decrease the passband insertion loss. The response of such a notch filter at 674 MHz is shown in the photographs of Figure 9. The notch depth was 65 dB and the pass-band insertion loss was 3 dB.

Determining Resonator Bandwidth

Roughly stated, loaded Q (Q_L) will be approximately equal to resonant frequency divided by bandwidth, and can be calculated from the RLC relationship shown in Figure 1C. Since the equivalent circuit for the resonator is a series resonant circuit, the bandwidth can be increased by increasing the source and/or load resistance, R_s and R_L in Figure 1C.

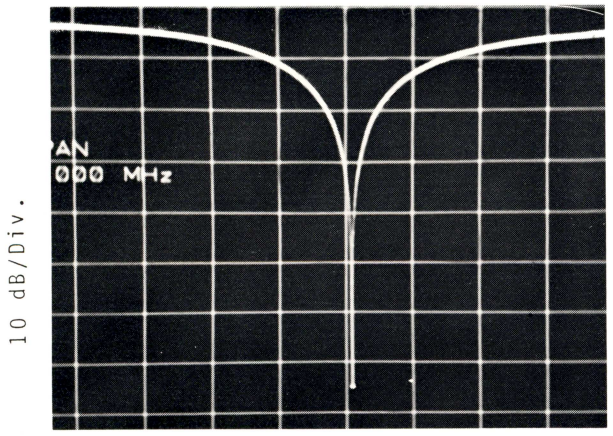
$$Q_u = \mu L/R_1 \text{ where } \mu = 2\pi fo$$

Loaded Q (Q_L) appears as:

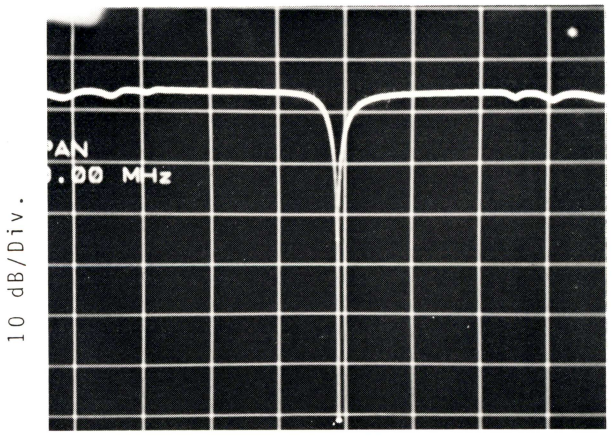
$$Q_L = \mu L/(R_1 + R_s + R_L)$$

Saw Filters

The SAW filters presently in use in TV IF's are simple transducer based filters with high insertion loss (20 dB typical). Such a high loss requires that additional gain blocks be added in front of the filter to avoid noise figure degradation. However, gain blocks in front of the IF filter are not protected from large interfering signals and are potential sources of cross modulation and intermodulation distortion.



(9A)



(9B)

Insertion Loss = 3 dB

Center Frequency = 674 MHz

Figure 9. SAW Resonator Notch Filter.

Table I
Broadband Band Pass Filters

	Demonstrated	Production	Projected Practical Limits
Center Frequency	1.0 MHz-2.75 GHz	10 MHz-1.0 GHz	10 MHz-2.0 GHz
Minimum Insertion Loss	0.65 dB	2.0 dB	1.0 dB
Maximum Fractional Bandwidth	100%	50%	100%
Sidelobe Rejection	70 dB	60 dB	90 dB
Minimum Bandwidth	100 kHz	100 kHz	50 kHz
Minimum Transition Bandwidth	100 kHz	100 kHz	50 kHz
Minimum Shape Factor	1.15	1.2	1.1
Triple Transit Suppression	55 dB	45 dB	60 dB
Amplitude Ripple	± 0.02 dB	± 0.05 dB	± 0.01 dB
Phase Deviation from Linear	± 0.1°	± 2°	± 0.1°

New Designs — New Applications

A second generation of mass producible SAW filters is now available. These filters offer low insertion loss, low triple transit distortion, independent tailoring of magnitude and phase response, excellent out-of-band rejection, and center frequencies approaching 1 GHz. Table I is a summary of absolute minimums and maximums both demonstrated and projected for this second generation of filters.

These devices are three-phase transducer based filters with three electrodes per wavelength on the substrate driven 120° out of phase. As a result, the matching network is more complex than that for first generation high loss filters, but the resulting improvement in system performance and the elimination of gain blocks is more than a fair trade-off. Figure 10B includes a schematic diagram of the equivalent circuit of a three-phase unidirectional transducer within the dashed lines. The necessary transformation from a single phase driving source to a three phase driving source is accomplished using a 60° Pi phase shifting network schematically illustrated in Figure 10A. The design of the network is straight-forward, as shown in Figure 10. An L-network is used to obtain the desired impedance match. The resulting matching network consists of three coils and one capacitor for each of the two three-phase transducers.

Wide-band Receivers

Given the low loss, excellent out-of-band rejection, and independent magnitude and phase response exhibited by the unidirectional low-loss filter, as well as a center frequency in the UHF band, a means of simplifying wide band receivers becomes evident. A common problem in broadband systems such as television receivers is spurious

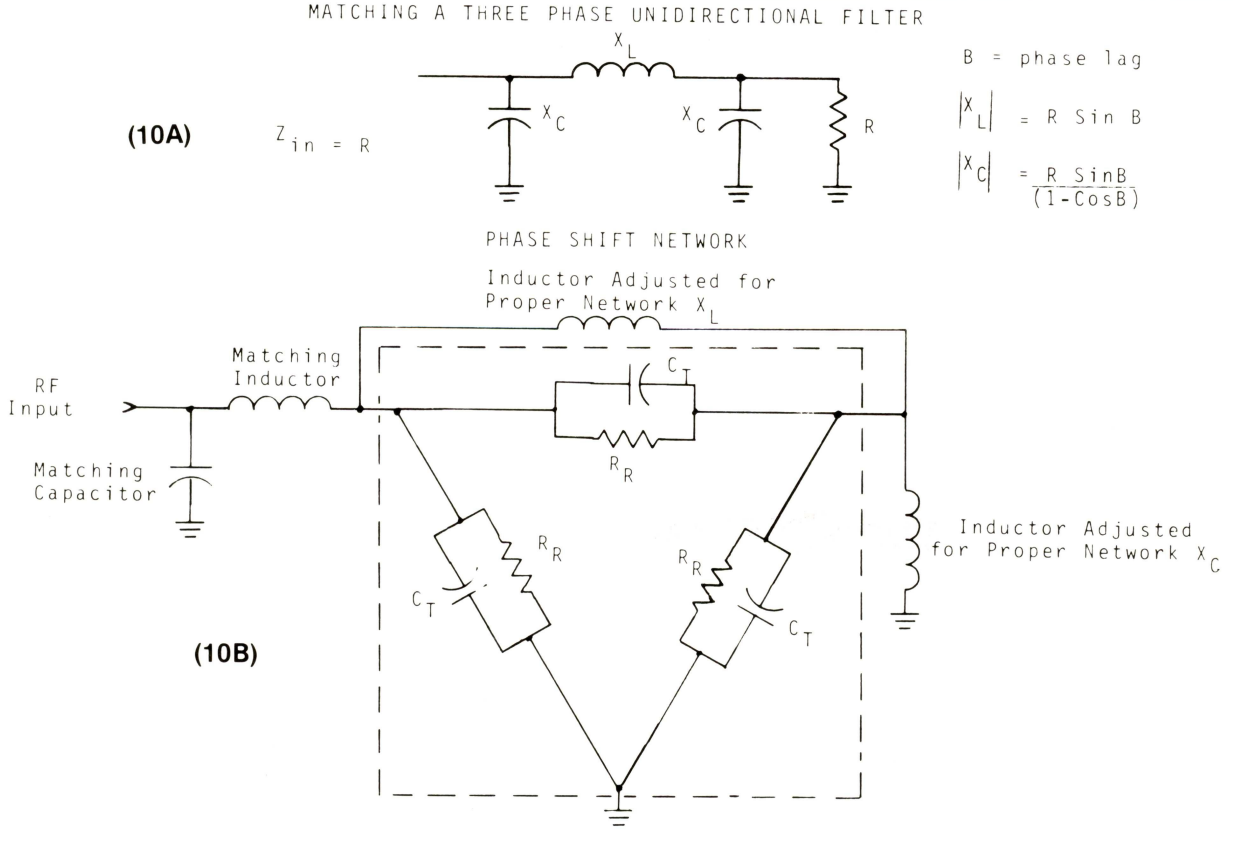


Figure 10. Matching and Phasing for a Three-phase Unidirectional Transducer.

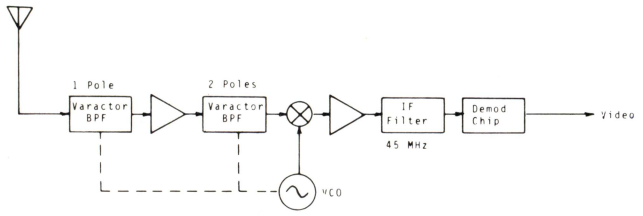


Figure 11. Varactor Tuned TV Receiver.

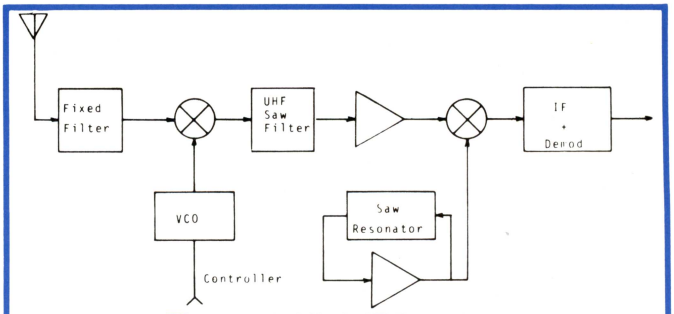
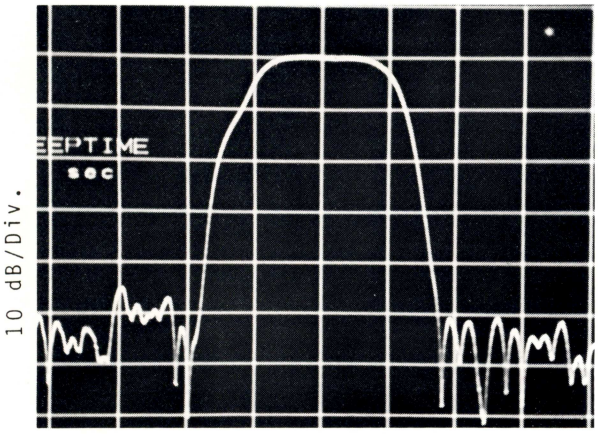


Figure 12. High IF Receiver.



Picture Carrier = 448.725 MHz (-4dB)
Insertion Loss = 6.5dB
Vestigial Weighting
Predistortion Phase Compensation
Sound Carrier = 13dB

Figure 13. FCC Low Loss SAW Filter.

receiver responses to IF related signals. Examples are IF beat, half-IF beat, image response, and local oscillator radiation. This problem is presently addressed using tunable RF filters such as the three pole varactor filters in TV front ends illustrated in Figure 11. However, UHF varactor filters are necessarily broad and have insufficient rejection to eliminate these responses in a system with a 45 MHz IF.

The low loss SAW filter makes it feasible to use a high first IF such as 450 MHz or higher to move the IF related spurious responses out of the desired frequency band. This makes it possible to use a fixed broadband RF filter to eliminate these responses. For example, a 450 MHz IF would have an image response at 900 MHz above the desired RF signal and an IF beat response at 450 MHz above the desired signal. Figure 12 is a block diagram of such a high first IF system. The low loss, UHF SAW filter is capable of rejecting adjacent channels in excess of 50 dB in a TV receiver with an IF of 450 MHz.

As shown in Figure 12, the high IF system would probably make use of double conversion to take advantage of IF gain and demodulator integrated circuits at IF frequencies such as 45 MHz. A SAW resonator oscillator would provide a low cost, stable second L.O. for such a system. The use of a high dynamic range mixer in conjunction with low RF gain minimizes cross modulation and intermodulation in the front end while providing a low system noise figure due to the low loss of the SAW filter. The SAW filter provides the

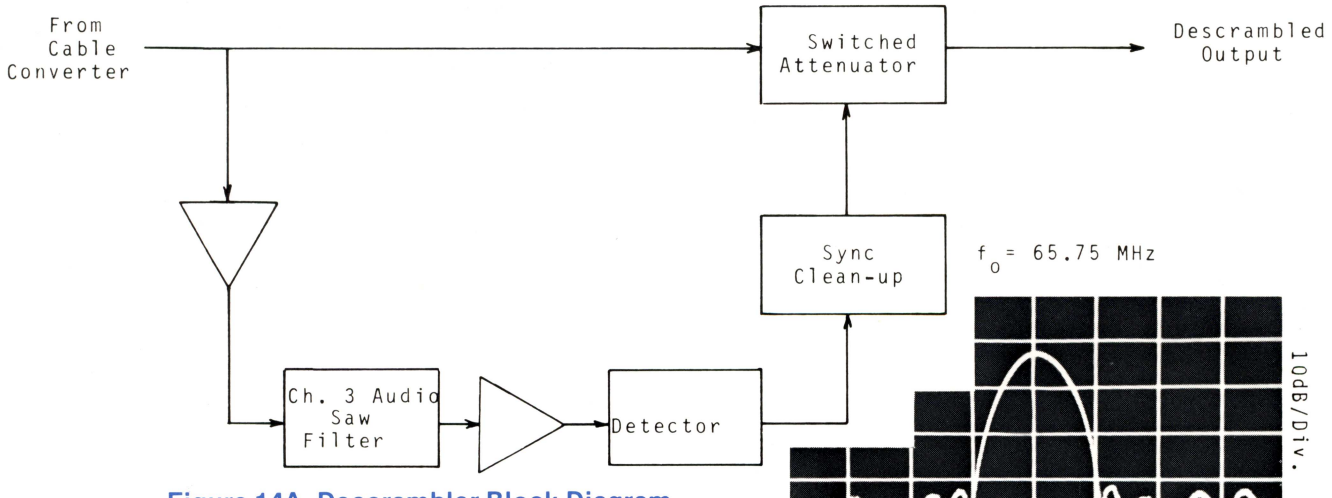


Figure 14A. Descrambler Block Diagram.

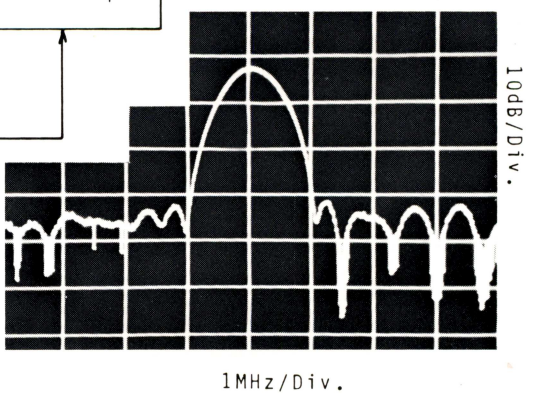


Figure 14B. Channel 3 Audio SAW Filter. ►

total filtering function as well as any needed phase compensation for predistortion and the like.

FCC Sponsored Receiver

Under a contract with the Federal Communications Commission, this author developed a high IF receiver to show that the UHF interfering signal handling capability of a TV receiver could be greatly improved with a simultaneous improvement in sensitivity or noise figure. The picture carrier frequency in the first IF was 448.725 MHz and a 402.975 MHz SAW resonator second L.O. converted the picture carrier to 45.75 MHz in the second IF.

The frequency response of the low loss SAW filter used in the first IF is included in Figure 13. The filter was vestigially weighted on the picture carrier side (upper side), phase compensation was included for transmitter phase pre-distortion, and adjacent channel rejection was in excess of 50 dB. The magnitude and phase weighting used for this filter also took into consideration other tuned element responses in the system. For example, the picture carrier is 4 dB down on the upper filter skirt, rather than the standard 6 dB, to compensate for a 2 dB roll off in the tuned circuit on the output of the second mixer. This new system exhibits a large improvement in performance over that obtained with present receivers. The performance parameters for this system will be released by the FCC at a later date.

The Low-loss Filter in Cable TV

Referring to Figure 14, another potential application for a low loss unidirectional filter is in the first IF of a cable TV converter to replace the four pole 612 MHz LC filters presently used. Such a filter would greatly reduce potential intermodulation and cross modulation distortion in the converter's second mixer and the TV receiver by rejecting adjacent channels. Alternatively, a low loss Channel 3 SAW filter can be used to reject adjacent channels on the cable converter output if distortion in the converter second mixer is not a problem but TV receiver distortion is a problem.

Other potential applications for such low loss SAW filters and/or resonator filters include satellite links and RF data modems.

"Standard" SAW Filters Still Working

First generation high loss filters, due to their simplicity, will probably continue to be used for applications where high loss does not adversely affect system performance. One example of this is the 45 MHz head end modulator filter which is used to carefully shape the spectral characteristics of cable TV signals. Another function which can be satisfied using a high loss SAW filter is that of a Channel 3 sound carrier filter in a TV descrambler circuit as illustrated in Figure 14A. In such a sync suppression system, the horizontal sync information is derived from the sound carrier. The filter is necessary to avoid interference from the video components of the TV signal which are too close to reliably filter out in mass production with LC filter techniques. Figure 14B is a photograph of the frequency response of a SAW filter designed for this purpose.

Many of these new uses for SAW devices were not even under consideration just a short time ago. As the technology matures, designers feel more secure in specifying them and gaining the improvements offered. No longer laboratory curiosities, SAW components have come of age and can be put to work in all of the above applications as well as many yet to be determined. □

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